



# High sensitivity and dynamic range Balance

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#### The Archimedes experiment

**Goal: To weight a Casimir multi-cavity while changing the reflectivity of its layers.** A change in the reflectivity corresponds into a variation of the internal vacuum state energy.



- High-T<sub>c</sub> superconductors (i.e. YBCO) as natural Casimir multi-cavities;
- Measurements taken in HV ( $10^{-8}$  mbar) at criogenic temperature (T = T<sub>c</sub>  $\approx$  90 K);
- · Reflectivity changed via thermal actuation;
- Flexible thin joints with low thermal noise;
- Two suspended arms to apply coherent noise subtraction;
- · Interferometric read-out system;
- Feedback control;
- Low seismic noise site.

The Archimedes experiment: expected signal

Weight contribution due to the total Casimir energy:

Weight variation (force signal):

For a disk-shape sample (Ø100 x 5 mm) of YBCO, according to the latest  $\Delta U_{Cas}$  estimation:

Spectral torque signal: Total arm-length: 1.4 m, Integration time: 10<sup>6</sup> s (~ two weeks)

$$\tau_{\rm s} = 3.5 \cdot 10^{-13} \text{ Nm} / \sqrt{(\text{Hz})}$$

$$\vec{F}_{s} = \frac{\Delta E_{Cas}}{c^{2}} \vec{g} = \frac{\Delta U_{Cas} V}{c^{2}} \vec{g}$$

 $|\vec{F}_s| \approx 5 \cdot 10^{-16} N$ 

$$C^2$$

 $\vec{F} = \frac{E_{Cas}}{2} \vec{c}$ 

#### The Archimedes experiment: expected sensitivity



#### 2018: Archimedes' working prototype



#### Scheme of Optical Lever and Interferometer

#### Important results: sensitivity reached on the ground





Reconstructed ITF sensitivity after an off-line OL noise subtraction

#### Important results: ground isolation



The balance has been suspended on a minus-k platform (thanks to sez. Ferrara). High frequency noise lowered and hence locking on ITF possible

#### Important results: 10 days data acquisition test



From december 23th to Januray 2nd – A test for robustness – High dynamic actuator (noisier) – Interesting sensitivity test at high frequency

#### Important results: sensitivity when ground-isolated



The Interferometer signal is the error signal for the loop. The Optical lever is at its electronic noise.

## What's next: Optical read-out system



The ORO on the prototype is the definitive one (no OL on the reference arm because it's not suspended yet).

### What's next: Optics



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For small oscillations  $\alpha$  :

$$\Delta \phi = 4 \frac{f}{l} \alpha^{2}$$
  
$$\Delta s = 4 \frac{f}{l} \alpha^{2} | d_{l,bs} + d_{bs,p} + l - f |$$

#### What's next: lower seismic noise site



In addition: A better seismic characterization of the site is a collateral product of Archimedes. It will be used to support Sos-Enattos candidature for ET site.

#### What's next: electronic requirements



At the moment the dominant noise in the actuation arise from the DAC. This noise is probably limiting our sensitivity at low frequencies. We expect to change out DAC with a low-noise 24-bit model (designed in Virgo).

Nonetheless, a fine CM positioning is foreseen to use low voltage in the feedback.

# What's next: mechanical requirements



Thin zone section: 100 µm x 10 mm

#### Joints vs threads



Low thickness/diameter is the fastest way to achieve a low frequency of resonance, but joints thinner than 100µm (x 10mm) are challenging to produce.

#### Towards thread-like joints



Thin zone section:  $-100 \ \mu m \ x \ 1 \ mm$  (Cu-Be a (Cu-Be a (Cu-Be a Cu-Be a Cu-Be a Cu-Be a Cu-Be a Cu-Be a Cu-Be a (Cu-Be a Cu-Be a Cu-B

(Cu-Be alloy / Aluminium) (Cu-Be alloy) → 25 mHz

Joints with smaller sections are scheduled to achieve resonances between 1-10 mHz.

#### CM position + fine tuning (remoted)



Arms are dimensioned to have their CMs superposed with joints' bending point within  $10x20 \mu m$ . Movable screws will ensure a fine CM repositioning with a range of  $\sim 50x150 \mu m$ .

In case of necessity the arms are predisposed for further counterweights.

# Repositioning CM by remote





#### Vertical Rotator

#### Horizontal Rotator

### Other fundamental assemblies



#### Remotely actuated Clamps



#### **Electrostatic Actuators**

### Archimedes apparatus (with short measurement arm)

R-Arm level

#### M-Arm level





#### Conclusions

- · Schemes of mechanical parts submitted in April for construcion;
- Purchase of commercial parts (stages, optical components) expected in the next two months;
- · Assembling expected in September.

In the meantime:

- Modal analysis of the support frames;
- Design of a new vacuum chamber with very high structural resonances (compatible with low noise UHV pumps).

# Thank you